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A PRELIMINARY INVESTIGATION OF THE PENETRATION OF SLENDER METAL RODS IN THICK METAL TARGETS

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A PRELIMINARY INVESTIGATION OF THE PENETRATION OF SLENDER METAL RODS IN THICK METAL TARGETS

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SUMMARY

Slender steel and tungsten-carbide rods were fired into copper, lead, and steel targets at velocities to about 11,000 feet per second. Values for the fineness ratio of the rods ranged from 6.0 to 12.7. For copper and lead targets, the impact is described as occurring in the undeformed-projectile region at the lower impact velocities and in the transition region at the higher velocities. For steel rods impacting steel targets, the impacts were described as occurring in the undeformed-projectile region of impact at all test velocities.

Rods impacting at velocities approaching the fluid-impact region were compared with the jets of shaped explosive charges. It was found that a rod produced a crater of twice the depth of that produced by a shaped-charge jet the same length as the rod. Furthermore, the craters produced by the rods were relatively wide cavities, with diameters comparable to depth, in contrast to the narrow holes formed by the jets. These differences are ascribed to increased secondary penetration for the rod impact, brought about by the low fineness ratio of the rods (10) compared to the jets (100).

INTRODUCTION

An investigation of the impact of small metal spheres into copper and lead targets for velocities up to 11,000 feet per second is reported in references 1 and 2. For impact occurring in the fluid region, the cavities are described as hemispherical in shape, deviating somewhat from this contour depending on the relative densities of the projectile and target materials. In contrast, the cavities produced by jets from shaped explosive charges having metal linings are very narrow compared to the penetration depth (ref. 3). To study the effects on target cratering of solid projectiles differing significantly in shape from spheres, an investigation of the impact of slender metal rods into thick metal targets at velocities to over 11,000 feet per second was conducted in the Ames hypervelocity ballistic range. The purpose of this report is to present a preliminary analysis of the target penetration and cratering data obtained.

NOTATION

- c speed of sound in target material, the velocity of propagation of a plane perpendicular wave in a slender prismatic bar, 11,670 ft/sec for copper, 4,025 ft/sec for lead, and 16,950 ft/sec for steel
- d diameter of rod projectile
- l length of rod projectile
- p penetration, measured from original target surface
- V impact velocity
- ρ mass density

Subscripts

- J jet
- P projectile
- T target

EXPERIMENTAL PROCEDURE

The experimental apparatus used in the impact tests is illustrated in figure 1. Metal rods were fired from a 0.22 caliber powder or light-gas gun into metal targets at velocities to 11,300 feet per second. The projectiles were of steel or tungsten-carbide and were stabilized in flight by aluminum fins.[1] Rod diameters varied from 0.040 to 0.060 inch, lengths from 0.25 to 0.60 inch, giving values for fineness ratio ranging from 6.0 to 12.7. The models were mounted in supporting sabots which not only guided them down the bore of the gun barrel but also provided protection from the damaging effects of the propellent gases. After launch, the several parts of the sabots were separated from the models as indicated in figure 1 and deflected aside to prevent them from damaging the targets. The projectiles were photographed in flight and intervals of time and distance were measured. The physical condition, attitude, and velocity of the models were determined from the above data. For the penetration data presented herein, projectile yaw at impact is believed not to have exceeded about 5°. The targets were thick and massive

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[1]The fins sheared off at impact. They were so light it is believed that they did not contribute to the penetration. The damage they caused was confined to the lip of the cavity.

compared to the cavities produced and, therefore, are considered representative of semi-infinite solids. All targets were alined with their faces normal to the projectile flight path. A detailed description of the experimental apparatus employed and the data reduction techniques used is provided in reference 1.

RESULTS AND DISCUSSION

The penetration of copper and lead targets by steel and tungsten-carbide rods and the penetration of steel targets by steel rods are presented in figures 2 and 3, respectively. Plotted is the penetration, in terms of projectile length, as a function of an impact parameter composed of the product of the ratio of projectile to target density and the ratio of impact velocity to speed of sound in the target material. The latter ratio is termed the "impact Mach number." Choice of the projectile length for reduction of the rod penetration data was made because, first, the depth of penetration of shaped-charge jets is proportional to jet length (ref. 3) and, second, for correlation of penetration, the results of certain impact investigations have indicated that the projectile dimension to be used is that measured along the line of flight (e.g., see ref. 2). The impact parameter selected for the abscissa of figures 2 and 3 is that previously used in reference 1 to correlate the penetration of spheres of various metals in copper and lead targets.

In figures 2 and 3, the faired curves are meant to illustrate only the general trend of the data and may not be indicative of the penetration trend for any one specific projectile and target combination. Individual fairings of the penetration data for each combination were not attempted primarily because of the limited number of data points. Also, a certain amount of scatter is present in the experimental data although not a great deal more than displayed by the sphere penetration data reported in references 1 and 2. Projectile yaw (a variable not present in the sphere tests), even though no greater than about 5°, may contribute to this scatter. Although the scope of the investigation was limited and although experimental scatter is present, some general remarks about the data can be made. The impact parameter used in figure 2 seems to be an adequate choice for comparing rod penetration in copper and lead for two reasons. First, for the steel rods of fineness ratio 8.5, the penetrations in the copper and lead targets are in reasonable agreement and, second, for any one target material, the penetrations of the steel and tungsten-carbide rods are much the same. The effects of a change in projectile fineness ratio on target penetration are not clear from the data of figure 2 primarily because fineness ratio was not varied over a sufficiently wide range. It might be expected that for a given projectile length, penetration would increase with decreasing fineness ratio because the increased weight of the rod would increase the secondary penetration, as discussed subsequently. No such conclusion can be drawn from the penetration of the steel projectiles but a tendency toward this is evident from the few data points obtained with tungsten-carbide rods of different fineness ratios. In any case, the data suggest that the variation of penetration depth with fineness ratio is small within the scope of the present investigation.

Examination of the general trend of the rod data of figure 2 indicates that the penetration increases, initially, fairly rapidly with increase in the impact parameter and then, above a value of about 0.5 for the abscissa, increases more slowly. This variation is not surprising in view of the results of reference 2. In reference 2, impact was described as falling in one of three regions depending on the striking velocity, and it was shown that the variation of penetration depth with velocity was different for the different regions. In figure 2 the variation of penetration suggests that impact occurred possibly in two such impact regions with the boundary between the regions being located in the vicinity of the bend in the faired curve. Shown in figure 2 is a photograph of a cavity, typical of low-speed impact, made by a steel rod striking a copper target at 3,420 feet per second. The cavity is barely wider than the diameter of the projectile, and about one-third of the rod was found to be imbedded in the target at the bottom of the cavity. In the region of this datum point, the slope of the faired curve of figure 2 indicates the penetration varies as the $4/3$ power of the impact parameter. From both the shape of the cavity produced and the $4/3$ power variation of penetration, it would appear that for the data presented in figure 2 for values of the abscissa of 0.4 and less, impact occurred in the undeformed-projectile region as described in reference 2 even though the rod projectile did break. The use of the word "undeformed" to describe low-speed impact is suitable apparently only when the impacting bodies are spheres or artillery projectiles of low fineness ratio.

The data of figure 2 for values greater than about 0.5 for the impact parameter should fall in the transition region of impact described in reference 2. This is the region where the projectile completely breaks up but projectile and target strength still influence penetration and cavity shape. Shown in figure 2 is a photograph of a cavity produced by a steel rod striking a copper target at 11,330 feet per second. The cavity is very much wider than the projectile diameter and nearly twice as deep as the length of the impacting rod. That this type of impact is different from that occurring at the lower velocity of 3,420 feet per second is quite apparent. Measurements of the cavity volume from the photograph cross sections indicate the volume of the cavity at the lower velocity to be only a little greater than that of the impacting rod, whereas the volume of the cavity produced at an impact velocity of 11,330 feet per second is more than two orders of magnitude greater than the volume of the projectile. Also of interest is the bottle-shaped appearance of the cavity with the diameter at the bottom significantly greater than the diameter at the target surface.

A third type of impact described in reference 2 is that in the fluid-impact region where the impact pressure is orders of magnitude greater than the strength of either the target or projectile with the result that both act as if they were fluids. For the data of reference 2, the boundary between the transition and fluid impact regions occurred at a value of the impact parameter about five times greater than that for the boundary between the undeformed-projectile and transition regions. If this relation of the boundaries holds for the data presented in figure 2, then fluid impact would occur above a value of about 2.0 for the impact parameter which, as can be seen, represents the upper limit of the data. The cavities obtained at this value of the impact parameter are no longer necked in at the target surface but instead are fully opened to the maximum width of the cavity. This is perhaps indicative of the approach of the fluid impact region. It would appear from the data presented in figure 2 that the impacts produced by slender rod projectiles follow the same pattern of change through the regions of impact as observed previously for impacts produced by spherical projectiles. It should be pointed out that the impact parameter employed was derived to correlate penetration for impact occurring in the fluid region. That this parameter seems to correlate the penetration in copper and lead targets by metal rods for impact occurring in the transition region may be because copper and lead are soft, low-strength metals compared to the rods. From figure 3, it is seen that the variation with velocity of the steel target penetration is the same as that noted for the copper and lead target data for low impact velocities, namely, with the 4/3 power of velocity. Also, the target cavities are small and narrow. The above observations suggest that the type of impact in the steel targets falls in the previously mentioned undeformed-projectile region. A photograph of the cross section of the cavity obtained at the highest impact velocity is shown in figure 3. The cavity volume is seen to be several times greater than projectile volume which may be indicative of the approach of the transition region of impact.

It is apparent that the steel target data do not correlate with the copper and lead target data. Correlation could not be expected since the impact parameter employed was derived for impact in the fluid region and the steel target data of figure 3 fall well outside this region.

It is interesting to compare the cavities produced by jets from shaped explosive charges with those produced by rods impacting at high speeds. From shaped-charge theory, the penetration of a jet into a target is given as

$$p = l_J \left(\frac{\rho_J}{\rho_T}\right)^{1/2}$$

regardless of the jet velocity (ref. 3). The experimental evidence of reference 4 supports this result. Also, the cavities are described as being very narrow compared to the depth of penetration. These results contrast markedly with those for high-speed impact of rods. Refer, for example, to the photograph in figure 2 of the target for rod impact at 11,330 feet per second. The penetration is more than twice that given by the above shaped-charge expression and the cavity is obviously not narrow but instead broad compared to the penetration depth. It is believed that the differences between the rod and shaped-charge cavities are due to the increase in the ratio of length to diameter from 8.5 for the rod to more than 100 for the shaped-charge jet. During the initial phase of the impact, a certain amount of the target material is set in motion and the momentum of this material causes it to move away from the point of impact producing what is usually termed secondary penetration. Since the rods employed in the present investigation were an order of magnitude thicker than a shaped-charge jet of comparable length, it seems reasonable to suppose that a rod impacting at high speed would set more target material in motion than would a jet with a resulting greater secondary penetration.

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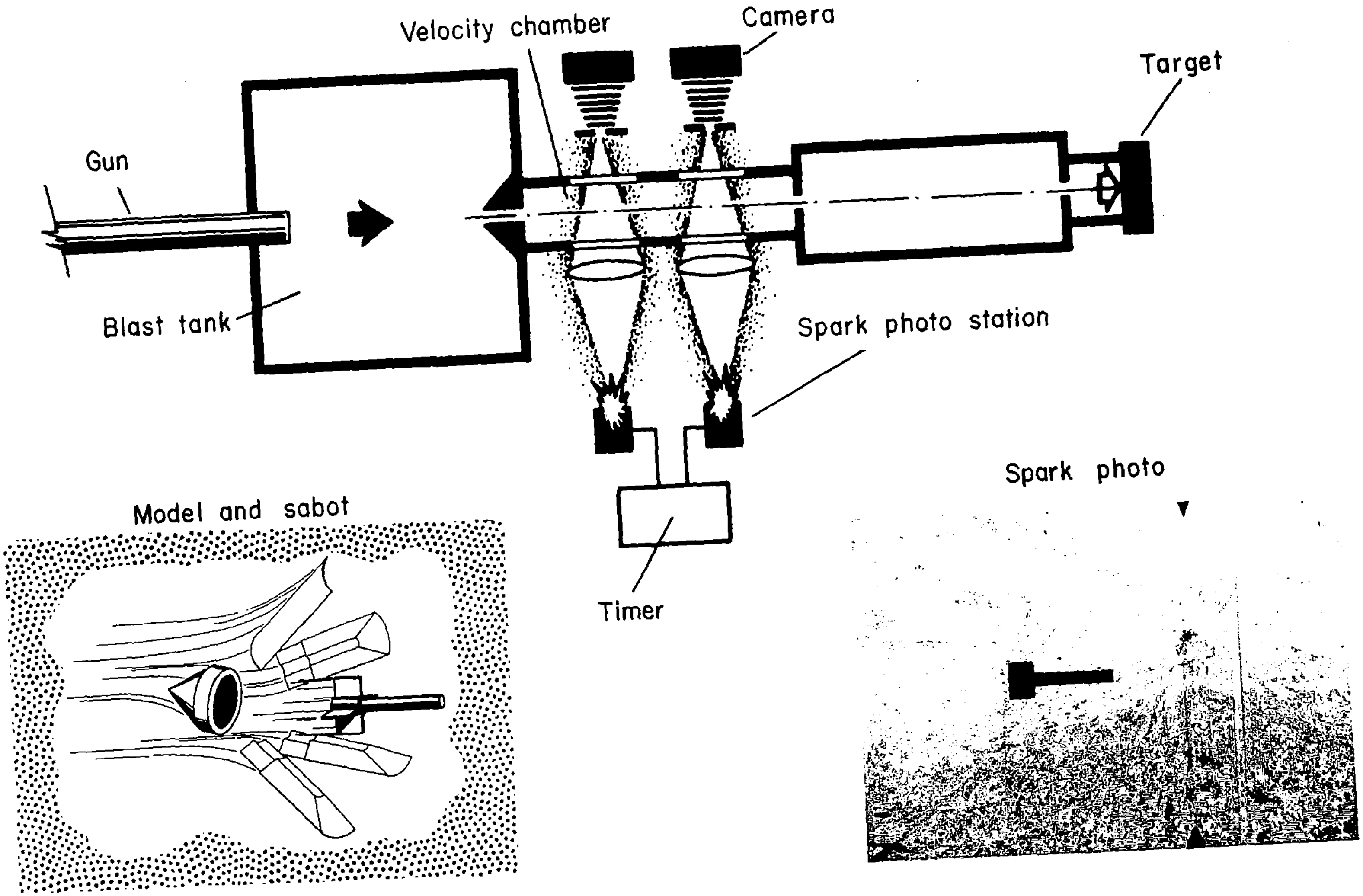

Figure 1.- Test apparatus.

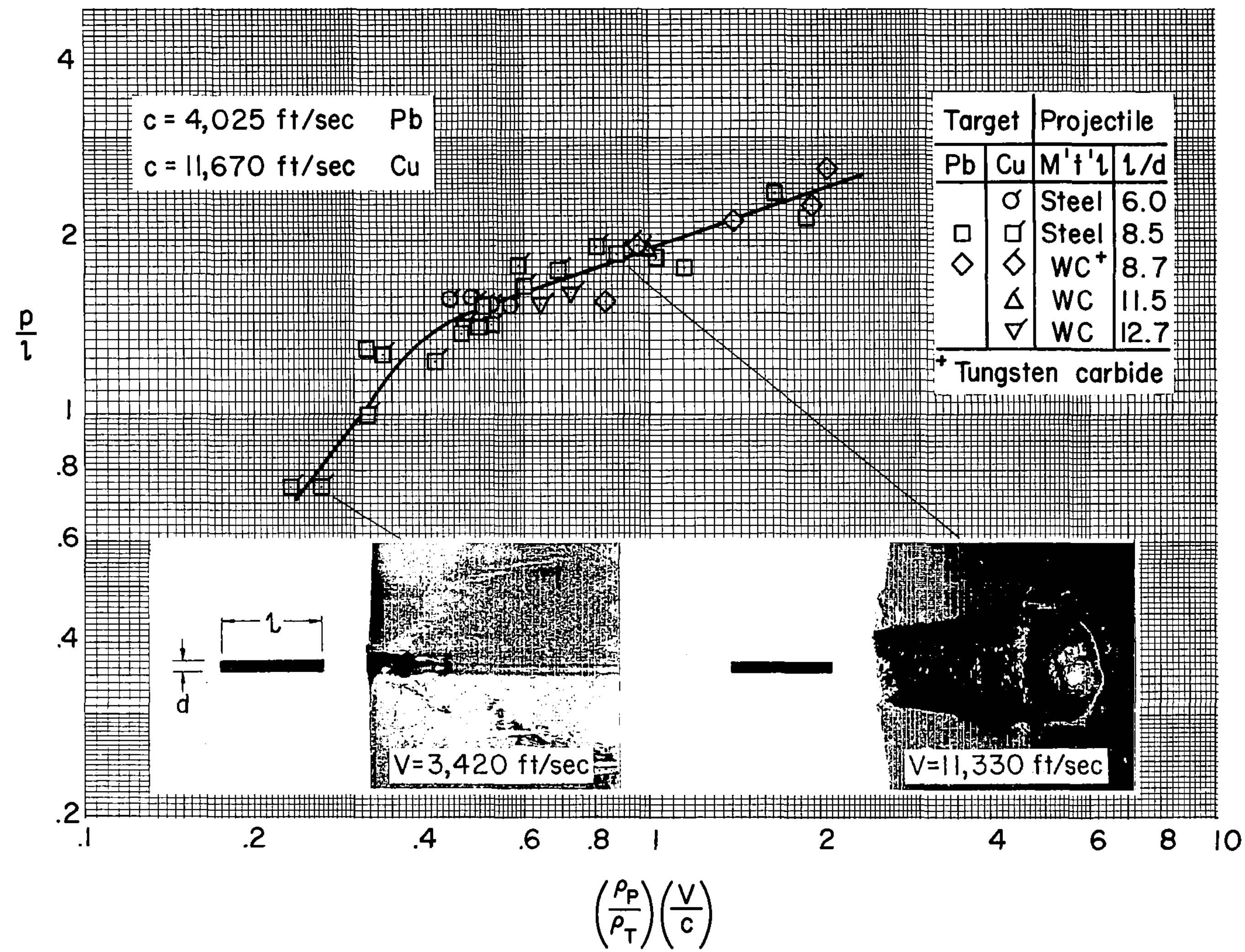

Figure 2.- Penetration of copper and lead targets by steel and tungsten-carbide rods.

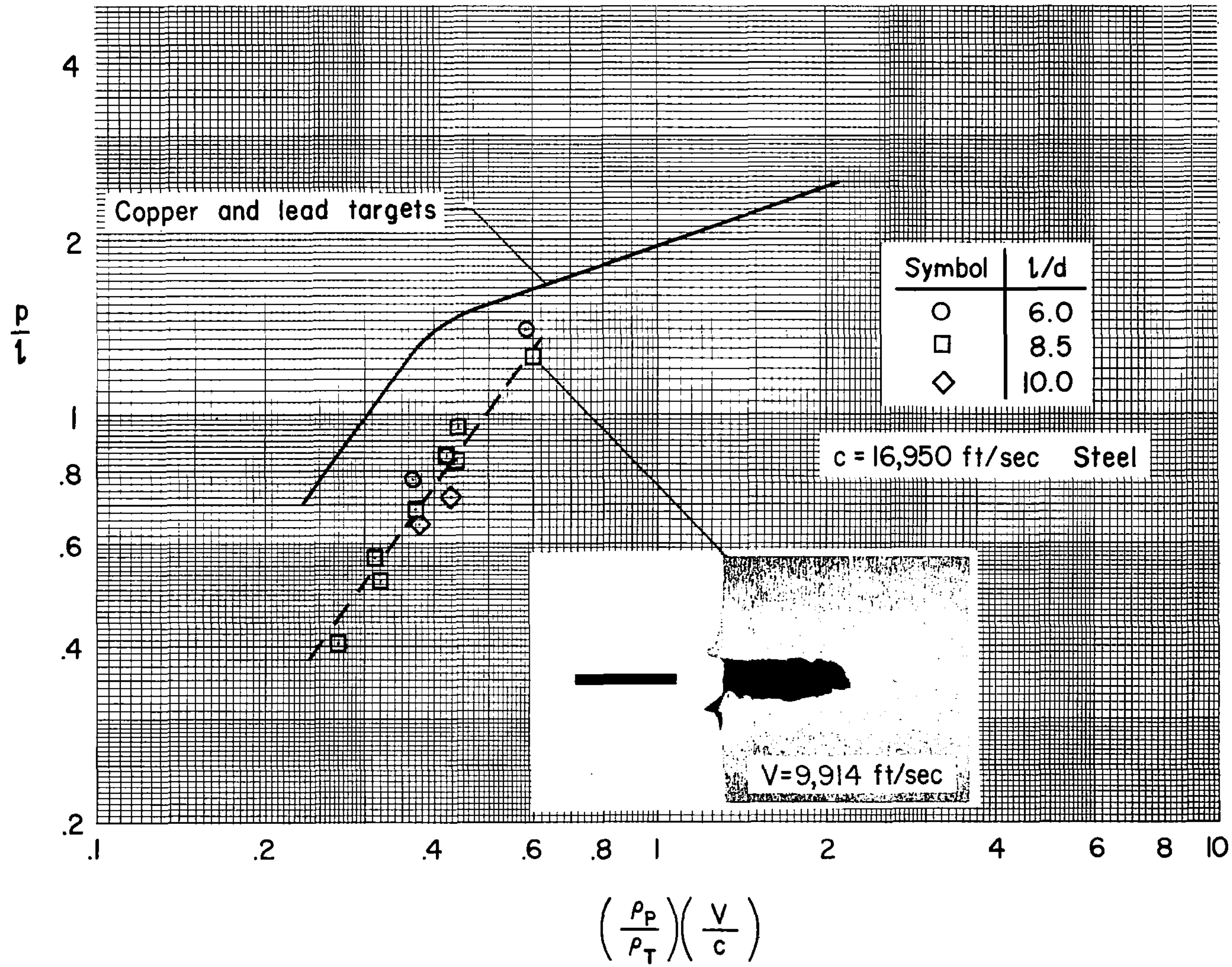

Figure 3.- Penetration of steel targets by steel rods.

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